Radiative capture measurements for transmutation of waste

-- and can RIA help ?

Bob Haight

LANCE-3

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Outline

- ATW (or RTW) -- what is needed
- What could RIA add?

Transmutation of waste -- what is needed?

- Isotopes -- depends on the plan, but for sure:
  - minor actinides
  - fission products
  - all produced in quantity and relatively long-lived (?)
    - i.e. not far from valley of stability
- Transmutation reactions
  - fission
  - capture
  - E_n < a few hundred keV (fast reactor spectrum)
- Criticality concerns
  - fission c/s, nu-bar, fission neutron spectra, moderation, capture..

What can RIA add for understanding radiative capture?

- Neutrons -- maybe -- at beam stop
- Otherwise
  - charged particle data as physics input to reaction models
    - nuclear level densities
    - nuclear spectroscopy
    - gamma-ray strength functions
    - optical model
  - production of target material in a cleaner way than reprocessing reactor waste -- make it and take it to a neutron facility
- As a substitute source for stable isotopes

Radiative capture of neutrons

- Direct capture (important generally at higher energies)
  - and related mechanisms such as direct-semidirect
    can be investigated by proton capture in inverse
    kinematics,   e.g. ^{99}Tc + p --> ^{100}Mo + γ
- Resonance capture (important at transmutation energies)
  - isolated resonances at eV energies

    need neutrons!

  - average over many resonances

    $$\sigma\,(n,\gamma)\ =\ 2\,\pi^2\,\lambdabar^2\ \Gamma\gamma\,/\,D_0\quad\text{(s-wave)}$$

    therefore need level densities at neutron separation
    energy -- for fission products, this is generally
    lower than for nuclei close to valley of stability

Radiative capture above resolved resonances

Competes with neutron emission and perhaps other channels. To calculate:
(1) need good optical model for $s_{c,cn}$
(2) need gamma-ray strength function for $T_{c'}$
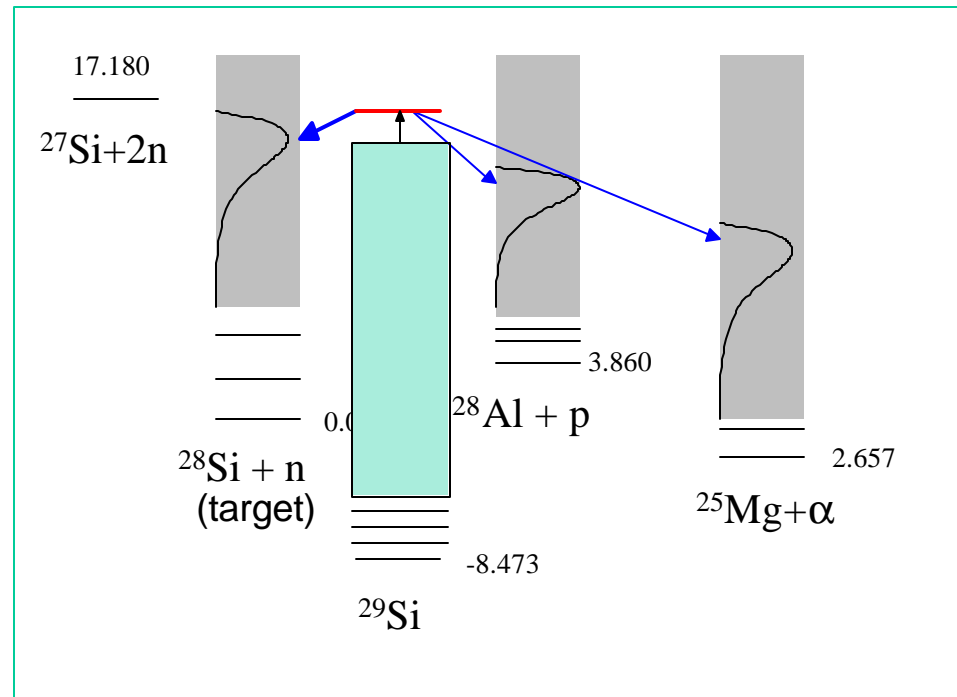
$$s_{c,c'} = s_{c,cn} \cdot \frac{T_{c'}}{S\,T_{c''}}$$

Level density

$$T_{c'} = S\,T_{c'}(E_n^*) + \int f_{c'}(E_n^*)\,r(e)\,de$$

Level density can be very low at neutron separation energy for neutron-rich nuclides but ATW nuclides are not so neutron rich

Nuclear levels in a "typical" nucleus very far from the valley of stability
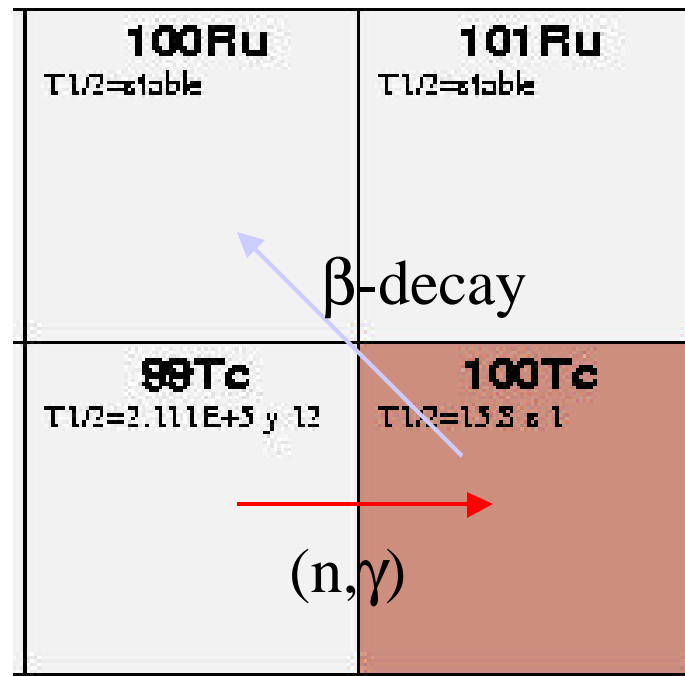
There sure are a lot fewer bound levels and level density for resonance neutron capture is very low!!
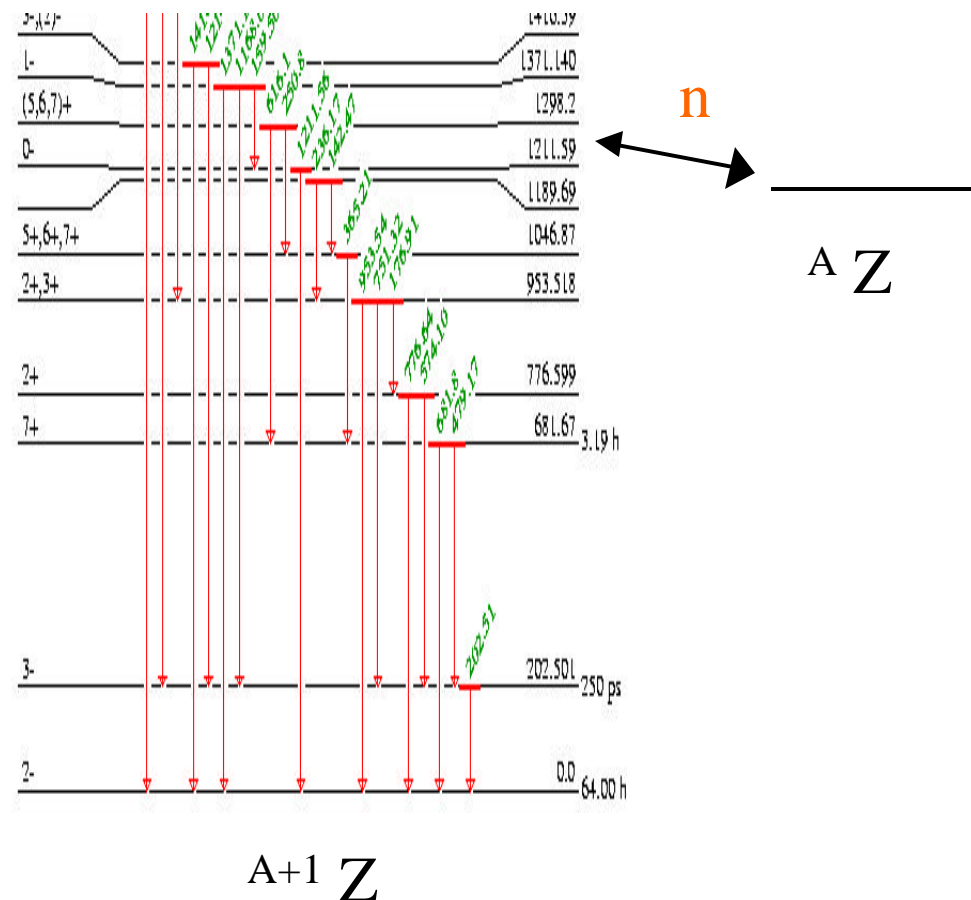
How can RIA be used to address these problems ?

- Fission product nuclides easily available
  - allows systematic studies across wide range of isotopes
- Actinides available (in lesser quantity?) but cleaner perhaps than from reprocessing
- Beams of nuclides well suited for experiments in inverse kinematics
- Experimental approaches will be extensions of proven techniques

# Destruction of ^{99}Tc

Destruction of ^{151}Sm

151Eu	152Eu	153Eu	154Eu
T1/2=stable	T1/2=13.537 y 6	T1/2=stable	T1/2=8.593 y 4

150Sm	151Sm	152Sm	153Sm
T1/2=stable	T1/2=90 y 8	T1/2=stable	T1/2=46.27 h 1

(p,n)

(n,γ)

148Pm	150Pm	151Pm	152Pm
T1/2=53.08 h 5	T1/2=2.68 h 2	T1/2=28.40 h 4	T1/2=4.12 m 8

148Nd	149Nd	150Nd	151Nd
T1/2=stable	T1/2=1.728 h 1	T1/2>1.1E19 y	T1/2=12.44 m 7

Radiative capture models can be tested

example: direct capture for fast nucleons

$$^{99}Tc + p \; -- > \quad ^{100}Tc \; + \gamma$$

$$or \qquad ^{99}Ru + n$$
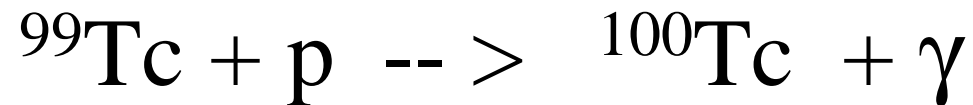
$$or \; ...$$

In inverse kinematics, the products all go forward and can be collected. Ratios of cross sections will result.

Conclusions

- Physics of neutron capture can be approached by experiments at RIA

- Pure isotopic samples might be prepared well at RIA

- Neutron capture cross sections difficult to measure directly at RIA